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Abstract
Public agricultural research in the United States is conducted by state agricultural experiment stations (SAES) and by the research agencies of the USDA. Both have research activities in every state. A vast amount of research and experiments has shown that the performance of plants and to a lesser extent animals, in which new technologies are frequently embodied, is altered by local geoclimatic conditions that differ within and between states. Basic research and livestock research to some extent lead to new knowledge or technologies that spill widely across state boundaries. Thus, public agricultural research produces knowledge that is both state specific and general.

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THE DEMAND FOR AGRICULTURAL RESEARCH BY STATE GOVERNMENTS

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Public agricultural research in the United States is conducted by state agricultural experiment stations (SAES) and by the research agencies of the USDA. Both have research activities in every state. A vast amount of research and experiments has shown that the performance of plants and to a lesser extent animals, in which new technologies are frequently embodied, is altered by local geoclimatic conditions that differ within and between states. Basic research and livestock research to some extent lead to new knowledge or technologies that spill widely across state boundaries. Thus, public agricultural research produces knowledge that is both state specific and general.

State government decisions are critical in the funding of SAES research and are a major factor in funding of public agricultural research in general. The federal government provides all of the funding for its own research activities in the states. The state agricultural experiment stations are funded from state government tax receipts and cash transfers. Both public sector and private sector transfers are involved. The portion of federal transfers that are Regular Hatch Act appropriations requires matching dollar-for-dollar with nonfederal funds. In 1984, these funds accounted for only 15% of total nonfederal SAES funding. Thus, the nonfederal funds exceeded greatly the amount needed to match Hatch funds. About 77% of the nonfederal funds are from state governments. Socially efficient state government decisions become complex, however, when interstate spillover effects are an important characteristic of public agricultural research.

Earlier theoretical and empirical studies of the demand for SAES research have primarily used competitive interest group theories of state government decision making (e.g., de Gorter and Zilberman; Guttman; Huffman and Miranowski; Evenson and Rose-Ackerman.[1/] These models are a reasonable specification for attempts to explain cross-sectional differences in the funding of public agricultural research. This approach seems, however, to have relatively little to say about what has driven the large increase in real public expenditures on agricultural research during the post-World War II period. This increase is slightly larger than 100% during 1950-85. These changes most likely have been driven by income and price effects operating through state government decision making.

The objectives of this paper are (i) to present a theoretical model of state government decision making on agricultural research in which this research produces state-specific private goods and public goods that spill across state boundaries, and (ii) to fit an econometric specification of the demand functions to a 34 year time series of data for each of the 48 contiguous states in the United States. The primary outcomes of this empirical analysis are estimates of price and income elasticities of demand for agricultural research in each state. In particular, we find that the demand for public agricultural research is highly price elastic (in fact, substantially larger than one in absolute value in most states) but full income inelastic, largely bounded between 0.2 and 0.8. The results also provide overwhelming evidence in favor of the joint-products model of the demand for agricultural research input, except for a few states where dairy research is relatively important. Thus, state governments cannot in general expect to borrow all of their agricultural research products or well adapted new technologies from research that has been conducted exclusively in other states.

The organization of the paper is as follows: Institutional background on the organization and funding of public agricultural research is first presented. Second, a conceptual model of the demand by state governments for agricultural research, when it is an input producing state-specific private goods and pure public goods, is presented. The third section summarizes the data and presents the econometric model of state government demand for agricultural research. The fourth section contains the econometric estimates of the demand functions and an evaluation of the results. The final section presents some conclusions and implications for future research.

Background

Public agricultural research in the United States is conducted by the USDA in its own research agencies--Agricultural Research Service, Economic Research Service, Forestry Service--and by the state agricultural experiment stations (SAES). Some of the USDA's own research activities are conducted in all states (Huffman and Evenson 1989, Ch. 3), and each state has its own agricultural experiment station. Almost all SAES are organized with a main station located on or closely associated with a land-grant university and one or more substations or regional stations. The latter stations are located to take advantage of differences in local geoclimatic differences that affect the performance and need for new technologies (Huffman and Evenson 1989, Ch. 3; Evenson 1989).

Spillovers or spillins of various types are a central characteristic of agricultural research (Evenson 1989). These can be summarized as interlocational, interfoci, intercommodity, and intersectoral based on the range of potential spills across geographical regions, broad fields of science, commodities, and sectors. For each class, direct and indirect forms can be distinguished. Of special interest to this study is the nature of interlocational spillovers or spillins. A vast amount of experimental and farm experience has shown that the performance of plants and animals (in which new technology is frequently embodied) is altered by differences in soils, temperature, moisture, and photoperiod characteristics of the producing environment.

Locational spillovers are greater between two locations having similar geoclimatic characteristics than between locations having dissimilar characteristics. Most states are located in more than one geoclimatic subregion, so the benefits of new SAES technology seem unlikely to be equally applicable to all areas even in a given state (Evenson 1989; Huffman and Evenson 1989). Some of the benefits will spill perfectly into other states located in the same subregion, but the degree of spillin decreases for states that are located a greater distance apart and have greater differences in geoclimatic characteristics.

The size of relevant regions for considering spillovers (spillins) of new crop and livestock technologies differs. Evenson (1989) presents some evidence that livestock research spills more fully over a larger area on average than crop research. Livestock technologies seem to be less sensitive to small changes in local climate; they are generally not very photoperiod sensitive. Thus, state specific benefits of research are relatively more important for crop than livestock research. The discoveries from livestock research seem to spill quite generally across state boundaries.

The federal government provides all of the funding for its own research activities at USDA research institutions. The state agricultural experiment stations are funded by state governments from state tax receipts and from transfers. Transfers from both the public and private sector are involved. Public sector transfers are from the federal government; some require matching, e.g., Regular Hatch Act funds, and others do not. Private sector transfers originate from commodity groups through allocations from check-off programs and from private sector companies. The SAES funds received from state appropriations and from Regular Hatch appropriations are largely unrestricted in terms of the type of research that can be undertaken. Much of the other federal funds and almost all research funded with private sector transfers are tied to specific research projects.

State government decisions are critical in the funding of SAES research and are a major factor in total public research funding. For example, in 1984 the total research budget of the USDA and SAES system was $1,575 million: the USDA's own research budget was $515.8 million, and the SAES system budget was $1,059 million or 67% of the total (Huffman and Evenson 1989, Ch. 2 and 3). The SAES system received $181 million of USDA administered federal funds, but only $114 million were Regular Hatch Act appropriations that required matching dollar-for-dollar with nonfederal funds. Regular Hatch funds were only 14.9% of SAES systems nonfederal funds ($114/$763x100), and nonfederal funds of the SAES system exceeded by 85.1% the amount required to match Regular Hatch funds. Thus, the nonfederal funds exceeded by a large margin the amount needed for matching federal funds.

The decision making and lobbying processes for the agricultural experiment station budgets are different in every state. In most states, the SAES budget is part of a university budget request that is sent to the state legislature. For example in Florida, Iowa, Minnesota, and North Carolina, the SAES budget is a separate line-item in the budget request that goes to the state legislature. This procedure establishes a direct link between legislative decisions and the SAES budget. However, in California and New York, the SAES budget does not appear in the budgets prepared by the University of California and the State University of New York systems. Furthermore, the director of the California agricultural experiment station is prohibited from lobbying the state legislature for funds.

In contrast, in Texas and at the New Haven (CT) station, the agricultural experiment stations are independent state agencies. The budget is prepared by the director, and he takes his request directly to the state legislature and lobbies for it.

The Conceptual Model

Because states are heterogeneous in geoclimatic conditions and in their institutional budget linkages between the SAES and state legislature, a state-specific model is suggested. The model is the basis for the empirical demand functions of state legislatures for public agricultural research. State governments provide private and public goods (or inputs) using available resources. It is well known that private collective action supplies sub-Pareto optimal quantities of a public good, and the government sector might do better (Bator; Olson; Cornes and Sandler, 1986). The Nash model presented is one of joint-products. (Also, see Cornes and Sandler 1984 and 1986; Andreoni; Sandler and Murdoch.) Most of the modern treatment of public goods and externalities has invoked Nash behavior when depicting an equilibrium allocation. Since states preserve much autonomy over their decisions on agricultural research expenditures, a Nash assumption, in which each state views the spillins of research benefits as given, is appropriate.

In this model, public agricultural research (SAES and USDA) is a publicly supplied input that produces two commodities: One commodity has pure private good characteristics, which provides state specific benefits, and the other is a pure public good, which provides benefits to the state where the research is conducted and which spills into other states. Although the ultimate beneficiaries from these commodities are primarily agricultural producers and consumers of agricultural products, we do not model the distribution of benefits between these groups. We believe that (over the time period of our empirical analysis) shifts in the distribution of benefits are not the primary explanation for changes in the demand for research in any particular state over time. An extensive examination of the effect of distribution of benefits on the demand for public agricultural research, however, can be found in de Gorter and Zilberman.[2/]

Each state legislature is assumed to have a well-behaved neoclassical utility function, with possibly different parameters that depends on a pure public good (Z_{1i}) and a pure private good (z_{2i}) both of which are produced from an input of public agricultural research (x_i) and an alternative composite publicly provided private good (Y_i):

(1) $U_i = U_i(Z_{1i}, z_{2i}, Y_i; E_i)$

where E_i is an environmental variable.[3/] Within state i, the production of z_1 and z_2 is represented simply as:

(2) $z_{1i} = f_1(x_i),\ f_1' > 0,\ f_1'' < 0,$

(3) $z_{2i} = f_2(x_i),\ f_2' > 0,\ f_2'' < 0,$

where primes denote first and second derivatives.[4/] The variable x_i denotes the ith state's voluntary and nonvoluntary contributions. Voluntary contributions are those decided at the state level (i.e., SAES), while nonvoluntary contributions are federal agricultural research expenditures (i.e., USDA) in the state. Since the public output z_1 is a regionwide public good, each state receives its output of z_1, and those of the other states so that the total quantity of the public output available for consumption by the ith state legislature is

$$(4) \quad Z_{1i} = z_{1i} + \tilde{Z}_{1i},$$

where $\tilde{Z}_{1i} = \sum_{j \neq i} z_{ij}$ is the total quantity derived from the other states and is termed an output "spillin" to the ith state. By (2), we have

$$(5) \quad \tilde{Z}_{1i} = \sum_{j \neq i} f_1(x_j) = h(\sum_{j \neq i} x_j),$$

in which $h(\bullet)$ is an aggregate function with $h' > 0$ and $h'' < 0$. Equations (4)-(5) imply that public agricultural research outputs, produced in other states of the region, are a perfect substitute for the state's own public research output.[5/]

The expenditures on agricultural research have been shown to have effects on agricultural productivity that start after 1 or 2 years and continue for 30-40 additional years (Pardee and Craig; Huffman and Evenson 1989; Knutsen and Tweeten). Thus, state tax collections are taken as exogenous to current decisions on x_i and Y_i . The ith state legislature's budget constraint is

$$(6) \quad P_x x_i + P_y Y_i = I_i,$$

in which x_i denotes voluntary and nonvoluntary contributions to state i. In (6), P_x is the price of public agricultural research, P_y is the price of the publicly provided private good, and I_i is the total budget (revenues) available to the ith state legislature, including intergovernmental cash transfers.[6] Nonvoluntary contributions are paid by federal taxes. To derive the ith state legislature's demand for regionwide voluntary and nonvoluntary contributions for agricultural research, we transform the budget constraint in (6) into a "full income" constraint by adding the value of input spillins, $P_x\tilde{X}_i$ both sides of (6), where $\tilde{X}_i = \sum_{j \neq i} x_j$ and includes voluntary and nonvoluntary contributions. The full income constraint is

$$(7) \quad P_xX_i + P_yY_i = I_i + P_x\tilde{X}_i \equiv \overline{F}_i$$

where $\overline{F}_i$ denotes full income. The quantity X_i denotes the total input from voluntary contributions, resulting from all state legislative decisions, and nonvoluntary contribution, which are the federal government's contributions, to public agricultural research, e.g., $X_i = \sum_i x_i$.

By (2) - (5), the utility function in (1) can be expressed as

$$(8) \quad U_i = U_i[f_1(x_i) + h(\tilde{X}_i),\ f_2(x_i),\ Y_i;\ E_i].$$

By the identity $x_i = X_i - \tilde{X}_i$, the utility function can be expressed in terms of its basic arguments or inputs:

$$(9) \quad V_i = V_i(X_i,\ Y_i,\ \tilde{X}_i,\ E_i),$$

where V_i is a hybrid utility function that embodies both the properties of the utility function $U_i(\bullet)$ and the production functions $f_1(\bullet)$, $f_2(\bullet)$, and $h(\bullet)$. The quantity $\tilde{X}_i$ is taken as a fixed magnitude in the utility function because it is not determined directly by state i, but it is important for determining the quantity of the pure private good that is available from X_i to state i. In a full income approach, a state legislature is assumed to behave as if it chooses Y_i and the aggregate quantity of X_i by:

$$(10)\quad \underset{\{X_i, Y_i\}}{\text{Max}} \ (V_i(X_i,\ Y_i,\ X_{\cdot i},\ E_i) \mid P_xX_i + P_yY_i = I_i + P_x\bar{X}_i),$$

in which the implicit constraint $X_i > \tilde{X}_i$ is imposed.

Under quite general conditions, the first-order conditions for optimal decisions on X_i and Y_i can be solved implicitly to obtain the legislature's demand functions:

$$(11)\ X_i^* = d_{X_i}(\bar{F}_i,\ P_x,\ P_y,\ \tilde{X}_i,\ E_i),$$

$$(12)\ Y_i^* = d_{Y_i}(\bar{F}_i,\ P_x,\ P_y,\ \tilde{X}_i,\ E_i),$$

Thus, in the joint-product model of the demand for publicly provided goods, the demand for agricultural research is driven by the price of agricultural research, the price of the alternative good, state government full income, a spillin variable, and an environmental variable. This is in contrast to the interest group model developed by de Gorter and Zilberman, which is more appropriate for explaining differences in a single cross-section.

A Nash equilibrium is reached when each of the n legislatures in a region demand an allocation X_i^* and Y_i^* such that $X_i^* = X_\ell^*$, for i, ℓ=1,...,n and $i \neq \ell$. That is, in Nash equilibrium, all states in a region must demand the same aggregate quantity of the public agricultural research input (but not of the private good Y). This Nash equilibrium for X in the joint-products model is apt to be sub-Pareto optimal, as in the Nash equilibrium in the pure public-goods model (Cornes and Sandler 1986, pp. 76-77). In the joint-products model, the neutrality of alternative sources of resources for funding public research does not hold. A reallocation of income so that a change of I_i is offset by an equal an opposite change in the value of spillins ($P_x\bar{X}_i$) does not leave a state's demand for agricultural research unchanged. (Also, see Bergstrom, Blume, and Varian; Sandler and Murdoch; Andreoni.) The reason is that a state only obtains more of the pure private good z_2 from additional research conducted inside its boundaries, not from additional research conducted in other states. In contrast, for a Nash equilibrium in a pure public-goods model, the source of resources does not affect the demand for agricultural research, i.e., $\tilde{X}_i$ would not enter equations (9)-(12), separately (Sandler and Murdoch, 1990, p. 879).

The Data and Econometric Model

Demand equations for public agricultural research are to be fitted separately for each of the 48 states in the contiguous United States for the period 1951-85.

The Data

A state's quantity of public agricultural research is derived as expenditures on SAES and USDA agricultural research in the state divided by a national index of the price of agricultural research. State expenditures on agricultural research are reported in United States Department of Agriculture-Cooperative State Research Service (USDA-CSRS), Funds for Research in State Agricultural Experiment Stations and Other State Institutions, for 1951-1966 and in USDA-CSRS, Inventory of Agricultural Research, for 1967 and later years. The U.S. Department of Agriculture's expenditures on its own research activities in the states were obtained from USDA-CSRS, Inventory of Agricultural Research, 1968-1985. For the earlier years, from 1951-1967, the data were derived for each state using data on SAES expenditures on agricultural research and the ratio of total public expenditures on agricultural research to SAES expenditures on agricultural research in 1968. Total public expenditures on agricultural research were obtained as the summation of state and federal expenditures.

The price index for agricultural research (P_x) is a weighted average of price indexes for scientists' time and for other nonlabor inputs. The index is taken from Huffman and Evenson 1989 (Ch. 2). It is a weighted average of an index of salaries of college and university faculty members (70%) (American Association of University Professors) and the wholesale price index (30%) (Executive Office of the President).7/ The weights between salaries and nonsalary items represent the 1951-85 period well. The wholesale price index was used for nonsalary items because of a need for representing prices of items that do not have a large labor cost share. The set of goods included in the index, however, is broader than the set of nonlabor inputs purchased by agricultural experiment stations.8/

The price index for the composite private good supplied by state governments (P_y) is the implicit GDP deflator for goods and services purchased by state and local governments (U.S. Dept. Comm., Statistical Abstract and Historical Statistics). This index is not perfect because it includes state government expenditures on agricultural research. Because these expenditures are a small percentage of total state government expenditures, the implicit GNP deflator covers primarily the nonresearch goods and services.

The cash budget constraint of the state legislature is measured as total state government revenue, including cash intergovernmental transfers (U.S. Dept. Comm., Statistical Abstract).

A classification scheme, based on geoclimatic considerations, was used to group states into similar geoclimatic regions, and these regional groups were used to define spillover variables. All classification schemes are somewhat arbitrary.9/ However, agricultural production patterns in each state were examined using production intensity maps (U.S. Dept. Comm. 1975). States having similar geoclimatic conditions and broadly similar production patterns were grouped into the same region. This classification scheme was constructed so that regional boundaries coincided with state boundaries; that it, a state was included only in one region and not partitioned into two (or more) regions. This seems to fit well into our framework of state legislative decision-making. Also, the regions seem large enough to capture the potential flow of research across states having similar conditions.10/ The regional classification of the states is presented in Table 1.

The Econometric Model

An econometric model is a specification that takes account of several special features of our data and economic model. The demand equations for agricultural research are permitted to have different parameters in each state. However, the variables that drive these demand equations over time are believed to be the same. State-specific fixed-effects that do not vary over time, e.g., the relative strength of producers' and consumers' groups, do not enter these demand equations, except through the intercept.

Because all states are trying to decide at approximately the same time on the demand for agricultural research, $\tilde{X}$ and $\bar{F}$ are random variables and are correlated with the random disturbances in the demand equations for public agricultural research by each state. An instrumental variable estimation procedure is to be applied and is an acceptable route to consistent estimates of the demand equations (Greene, p.300-302). In addition, annual time series data frequently exhibit momentum, which causes disturbances in behavioral equations to be correlated. This problem needs to be corrected to improve the reliability of test statistics and efficiency of the estimator (Greene, Ch. 15).

To take account of these special features, a three-equation model potentially having first-order autocorrelation of disturbances is specified:

(13) $\ln X_t^r = \beta_0 + \beta_1 \ln \bar{F}_{it} + \beta_2 \ln P_{xt}^* + \beta_3 \ln SPILL_{it}^r + \mu_{it}$

(14) $\ln \bar{F}_{it} = \gamma_0 + \sum_{\ell=1}^{n^r} \gamma_\ell \ln I_{\ell t} + \phi_1 \ln P_{xt}^* + \epsilon_{it}$

(15) $\ln SPILL_{it}^r = \delta_0 + \sum_{\ell=1}^{n^r} \delta_\ell \ln I_{\ell t} + \phi_2 \ln P_{xt}^* + \nu_{it}$

where

X_t^r = quantity index for total public (voluntary and nonvoluntary) agricultural research activity in region r during year t,

P_{xt}^* = relative price index for public research activity during year t, P_{xt}/P_{yt},

$SPILL_{it}^r$ = $X_t^r - x_t$, the real spillins of total public (voluntary and nonvoluntary) research to state i in year t, or the quantity of public in-kind transfers,

I_{it} = real state revenue, state government revenue divided by the implicit GDP deflator for state and local governments,

$\bar{F}$ = $I_{it} + P_{xt}^* SPILL_{it}^r$, real full income for state government i in year t,

β_is, γ_is, ϕ_is = unknown coefficients,

n^r = the number of states in region r,

ϵ_{it}, ν_{it} = random disturbance terms,

μ_{it} = $e_{it} - \rho e_{t-1}$, a random disturbance term represented by a first order autoregressive process, $|\rho| < 1$, $Ee_{it} = 0$.

The model, which is linear in the logarithms of the variables, outperforms a linear in levels specification, and the coefficients are elasticities.

Efficiency and good test statistics are desirable properties for equation (13), but they are not important for equations (14) and (15).[11] The latter two equations need only to provide consistent forecasts of lnF and lnSPILL, and these can be obtained from OLS estimates. Thus, the steps in the estimation process are as follows. First, equations (13)-(15) are fitted with $\rho = 0$, and the null hypothesis that $\rho = 0$ is tested. Second, if ρ is significantly different from zero at the .05 level, the estimate of ρ, $\hat{\rho}$, is used to transform the variables in (13), including the predicted values of ln F and ln SPILL. The first observation is transformed by $\sqrt{1 - \hat{p}}$. Equations (13)-(15) are then refitted using two-stage least squares.

In equation (13), if β_3 is not significantly different from zero, then the distribution of full income between cash and in-kind or spillin components is not important for determining a state's demand for public agricultural research. Thus, when $\beta_3 = 0$, the joint-products model reduces to the pure public goods model of the demand for agricultural research.

Although we have provided sound reasons why the coefficients of the demand equations for agricultural research will be different across states, homogeneity of response is a testable hypothesis. If some of the coefficients are not significantly different, then we can impose equality and reduce the number of different coefficients to be estimated and reported and increase the efficiency of the estimator.

The following null hypotheses are to be tested (against a negative alternative) for each of the 5 regions:

(16) $H_1 : \beta_{11} = \beta_{1j}$, for $j = 2, \ldots, n^r$,

(17) $H_2 : \beta_{21} = \beta_{2j}$, for $j = 2,\ldots, n^r$,

(18) $H_3 : \beta_{31} = \beta_{3j}$, for $j = 2,\ldots, n^r$,

(19) H_4: H_1 and H_2

(20) H_5: H_1 and H_3

(21) H_6: H_2 and H_3

(22) H_7: H_1, H_2, and H_3.

When a null hypothesis cannot be rejected, we will then impose equality of the coefficients across all states in a region and re-estimate the equations. If the null hypothesis is rejected, this is taken as evidence that the response elasticities really are different.

Table 1 reports sample mean values of variables used in the econometric model. The West region is the largest demander of public agricultural research for the period under analysis, and the Central region and South and Eastern Uplands rank 2rd and 3rd, respectively. California, Texas, Florida, and New York supply the largest quantity of public agricultural research. Rhode Island supplies the smallest. The Northeast relies unusually heavily upon the USDA for agricultural research compared to the other regions. It is, however, comprised of many small states in which dairy production is relatively important, and we expect dairy research conducted in one state in this region to spill easily across state boundaries. Also, the USDA's Beltsville Research Center is located in this region, and it is largely responsible for the agricultural experiment station being only 11% of the public agricultural research conducted in Maryland.

The Empirical Results

The state government demand functions for public agricultural research are fitted to annual data for 1951-1985 for each of the 48 states grouped into the 5 geoclimatic regions. They are obtained by applying the least-squares instrumental-variable estimation procedure which is implemented by fitting equations (13)-(15). Homogeneity of response elasticities across all states in a region are tested and reported in Table 2. For the Southern region and the Eastern Upland region, the null hypothesis that variable-by-variable equality of response elasticity cannot be rejected at the 5 percent significance level. For the Central region, equality across all states of the price elasticities and of the spillin elasticities cannot be rejected. However, equality of full income elasticities is rejected. In the Western region and Northeast region, all of the null hypotheses in equations (16)-(22) are rejected. Both of these latter regions are composed of an unusually large number of states, and the size of the state legislative budgets range from very small to very large. Furthermore, these two regions do include California and New York which seem to have unusually complicated budget request processes for the state agricultural experiment station and the Northeast also includes Maryland where the USDA's Beltsville research center is located.

Tables 3-7 report the final estimates of the state government demand functions for public agricultural research. Homogeneity of response elasticities is imposed based upon the tests reported in Table 2. The results taken as a whole are amazingly consistent with the joint-products model of state government decision-making on agricultural research. First, 42 of the 48 price elasticities are negative, and only one of the 6 that are positive is significantly different from zero at the 5 percent level. It is for Delaware which is an extremely small agricultural state. Second, all of the full-income elasticities, except one, are positive, and the one that is negative is not significantly different from zero at the 5 percent level. Third, all of the elasticities of spillin are significantly different from zero, except for 6 states. The exceptions are Maryland, New York, New Jersey, Pennsylvania, Kansas, and New Mexico. For these states, the pure public good model is the better theoretical paradigm. The first 4 of these states are in the Northeast region where dairy research and milk production are relatively important compared to cash crops.[12/] Livestock, especially dairy research, is expected to have a large spillin component or a large interstate public good component. This leaves only Kansas and New Mexico as deviating from expected outcomes.

Our research shows that state government demand for public agricultural research is unusually price elastic but is full income inelastic. The states in the Northern Plains region (Table 3) exhibit the most elastic price response, ranging from -2.6 to -6.2. In the Southern, South and Eastern Uplands, and Central regions, the price elasticity is -2.01, -2.13, and -1.54, respectively. In the Western region, the price elasticities are generally smaller than for states in the other regions. However, for the two states where the price elasticity is negative and greater than -1, it is not significantly different from -1.

Huffman and Miranowski obtained a price inelastic estimate for SAES research by state governments. Other studies of the demand for public agricultural research and most studies of publicly provided goods have been unable to come up with price data, and they therefore ignore the effects of price on the demand for these goods. Our study shows that state governments are very sensitive to the price of public agricultural research when they make decisions on the quantity demanded. Thus, ignoring the price elasticity would be ignoring one of the major determinants of changes in the demand for public agricultural research in the 48 states over the 34 years covered in this study.

In 46 of the 48 states, the full-income elasticity of demand for public agricultural research by state governments is between 0.2 and 0.8. These are income inelastic responses, but they are consistent with earlier estimates in the sense that they are positive. Wealthier states do spend more on public agricultural research than other states, and over the sample period, the large increases of state government full incomes have been a major factor for explaining the increase in the demand for public agricultural research. The earlier studies by Huffman and Miranowski, by Guttman, and by Rose-Ackerman and Evenson obtained income elasticities that were larger than one. These income elasticities, however, were fitting to quite different models, and were explaining real expenditures on SAES research using only a states's own cash budget constraint (which excluded in-kind transfers). Thus, we believe that the differences in income elasticity estimates are due primarily to differences in methods.

Excluding the states where the spillin elasticity is not significantly different from zero, all of the others are positive, except for Delaware. These positive and significantly different from zero elasticities for spillin show that state-specific private good aspects of public agricultural research are important factors for state government decisions on the demand for public agricultural research. Furthermore, this type of effect is consistent with what we believe about the composition of products produced by most public agricultural research (Evenson 1989; Huffman and Evenson 1989). State-specific benefits change the incentive structure since failure to do research will result in lower pay-offs because private benefits would not be available. The only way that a state can have larger quantities of the pure private good associated with public agricultural research is for more public agricultural research to be conducted within its boundaries. These benefits cannot spillin from other states. These state-specific private goods seem most important for crop as opposed to livestock or basic research.

Conclusions and Implications

This paper has presented a theoretical and econometric examination of the demand for public agricultural research by state governments. The empirical results showed homogeneity of price, full income, and spillin elasticities for the states in the South, and homogeneity of price and spillin elasticities for states in the Central region. States in other regions have a diversity of response elasticity magnitudes. Our results, however, showed a consistent pattern of price elastic and income inelastic demand for public agricultural research. Given the changes in the price of research and states' real full incomes over the 34 year period 1951-1985, these elasticities, along with the spillin elasticity, explain a large share of the increase in the demand for public agricultural research over this period. Except for a few, primarily dairy-product producing states, the results also supported the joint-products model of the demand for agricultural research input. Thus, states must conduct more agricultural research if they want more of the private good produced by agricultural research input. This seems to be one of the reasons why agricultural experiment stations have been successful for over 100 years in each of the states. State governments recognize that they cannot expect to borrow all of the useful products of research from activities conducted outside their state boundaries.

Future research will explore the degree of substitutability between USDA and SAES research and the weighting of research in other states in evaluating spillin effects. Also, other public allocation schemes than Nash will be examined. One alternative is the Lindahl cooperative decision-making scheme in which public research allocations are Pareto optimal.

FOOTNOTES

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1/Other studies include Peterson and Alston, Edwards, and Freebairn.

2/The median voter model is another possible model. For example, see Bergstrom and Goodman; Borcherding and Deacon; Dudley and Montmarguette. To implement the median voter model of the demand for publicly provided goods, the median voter is identified as the median constituent's income. This is a restrictive assumption. Furthermore, the median voter approach implicitly assumes that public good issues are of a single voting dimension.

3/This utility function imposes minimal restrictions on price and income elasticities. This is in contrast to the quasi-linear utility function chosen by de Gorter and Zilberman. The latter function eliminates income effects. This is very restrictive because we believe that non zero income effects are very important for explaining changes in the demand for public research overtime.

4/This is clearly one reasonably restrictive specification of the technology for joint production. The function $f_1(\cdot)$ can be allowed to differ by state, but such a complication would not alter our demand equations or empirical model.

5/Perfect substitutes is a strong assumption. An attempt to allow for imperfect substitution possibilities would complicate the modeling significantly. Future research might explore the effects of a less restrictive assumption.

6/The model that is presented is one of the voluntary contributions of state governments to public agricultural research and nonvoluntary federal contributions. The assumption is made that federal provision of agricultural research is self-financed by a lump-sum tax on the states. Clearly, other taxes are possible and they would change the model. Of course, a more elaborate model consisting of two level (federal vs. state) decision making on public agricultural research could be developed. This more complex model, however, is left to future research.

7/Pardee, Craig, and Hallaway (1987) present a discussion of agricultural research deflators.

8/The implicit GDP deflator for goods and services purchased by state and local governments was not used as the deflator for public agricultural research because the share of professional staff time is significantly larger for research. The implicit GDP deflator for state and local governments was not used ot deflate nonscientist items because it has a labor cost share that is about 57 percent.

9/The primary <u>alternative</u> specification is one where the relevant region for spillover effects for a given state is for the spills to flow to the other 47 states. The fit of this model, however, was not good when compared to the ones where states are grouped into five regions based on geoclimatic consideration. The results of the single region specification are available from the authors on request.

[10]/Our classification scheme draws from two classification schemes already used in the literature. First, the USDA's Economic Research Service (ERS) production regions groups states into relatively small regions, sometimes with only two or three states and leads one to suspect that spills are not fully contained in the region. Second, Evenson (1982), uses a classification scheme based primarily on geoclimatic considerations and does not follow state boundaries. A state can be in two or more regions. Placing one state in two or more regions seems inappropriate for our framework when state legislatures make decisions, given expenditure decisions of other states in the same region. Hence, neither of these alternative classification schemes seemed to be an appropriate specification of regions in which agricultural research spillover effects occur.

[11]/Of course, there are many other instruments that could be employed.

[12]/In 1980 milk is 79% of the value of grain and milk production in the Northeast region. Grain production is 50% or larger share in the other regions.

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Table 1. Mean Public Agricultural Research Investment and Selected Other Variables, 1951-1985.

Region/State	Total quantity of public agricultural research (SAES & USDA) (in thousands of 1984 $)	SAES share of public agricultural research (%)	State government full income (in $ 10^5)	Public agricultural research spillin (in $ 10^5)
1. Central	267,981	83.8		
Indiana	26,738	81.6	12.60	1.80
Illinois	41,493	85.7	26.98	1.66
Iowa	33,332	83.2	8.76	1.75
Michigan	27,747	81.8	28.45	1.79
Missouri	32,767	84.5	10.75	1.19
Minnesota	34,110	83.8	12.94	1.74
Ohio	25,793	81.6	26.55	1.80
Wisconsin	46,001	86.2	13.71	1.64
2. Northern Plains	71,573	87.7		
Kansas	23,021	89.4	6.12	0.37
Nebraska	20,725	88.6	2.89	0.39
North Dakota	17,610	87.4	3.74	0.41
South Dakota	10,217	82.7	2.02	0.46
3. West	334,344	83.4		
Arizona	24,050	78.5	6.55	2.45
California	135,751	93.2	70.11	1.49
Colorado	26,862	78.9	7.88	2.44
Idaho	16,118	76.0	3.31	2.51
Montana	24,127	78.5	5.18	2.45
Nevada	17,762	71.6	3.37	2.52
New Mexico	6,836	69.4	4.29	2.58
Oregon	31,743	81.1	8.32	2.39
Utah	13,865	74.7	4.56	2.52
Washington	30,491	81.2	14.25	2.39
Wyoming	6,739	69.3	2.92	2.58

Table 1. (Continued)

Region/State	Total quantity of public agricultural research (SAES & USDA) (in thousands of 1984 $)	SAES share of public agricultural research (%)	State government full income (in $ 10^5)	Public agricultural research spillin (in $ 10^5)
4. Southern	170,438	86.7		
Arkansas	22,193	82.6	5.53	1.66
Louisiana	47,015	88.8	13.71	1.06
Mississippi	16,174	77.6	4.63	1.88
Oklahoma	17,807	80.7	8.96	1.29
Texas	67,249	90.6	26.93	.95
5. South and Eastern Uplands	242,162	81.3		
Alabama	12,765	70.0	9.91	1.79
Florida	61,812	87.2	16.41	1.99
Georgia	49,547	84.5	12.50	2.10
Kentucky	17,195	76.9	9.63	2.37
North Carolina	39,041	82.5	14.49	2.19
South Carolina	17,726	77.1	8.09	2.37
Tennessee	14,556	75.1	10.19	2.39
Virginia	18,969	77.2	12.40	2.36
West Virginia	10,551	72.8	6.81	2.43
6. Northeast	186,038	66.6		
Delaware	4,185	67.4	2.64	1.74
Connecticut	9,738	74.8	8.88	1.73
Maine	6,034	69.6	3.75	1.76
Maryland	40,038	11.0	10.72	1.17
Massachusetts	8,105	71.9	17.20	1.75
New Hampshire	4,188	67.5	2.57	1.78
New Jersey	14,790	78.2	16.05	1.62
New York	56,055	88.8	59.38	1.30
Pennsylvania	36,151	85.1	31.62	1.47
Rhode Island	2,782	64.1	3.72	1.79
Vermont	3,972	67.2	2.14	1.78

Table 2. F-test on the Equality of Coefficients Across States in a Region (5% significance level)

	Null hypotheses											
	H_{01}: $\beta_{11} = \beta_{1j}$, $j=2,\ldots,n^r$				H_{02}: $\beta_{21} = \beta_{2j}$, $j=2,\ldots,n^r$				H_{03}: $\beta_{31} = \beta_{3j}$, $j=2,\ldots,n^r$			
Region	Sample F-value	Degrees of freedom	Critical F-value	Con-clusion	Sample F-value	Degrees of freedom	Critical F-value	Con-clusion	Sample F-value	Degrees of freedom	Critical F-value	Con-clusion
Central	0.397	7,240	2.04	Unable to reject	4.779	7,240	2.04	Reject	0.591	7,240	2.04	Unable to reject
Northern Plains	11.011	3,124	2.68	Reject	37.008	3,124	2.68	Reject	12.581	3,124	2.68	Reject
West	1.889	10,330	1.86	Reject	9.191	10,330	1.86	Reject	3.195	10,330	1.86	Reject
Southern	0.239	4,150	2.43	Unable to reject	0.539	4,150	2.43	Unable to reject	0.244	4,150	2.43	Unable to reject
South & E.Central Uplands	0.114	8,270	1.97	Unable to reject	0.804	8,270	1.97	Unable to reject	0.231	8,270	1.97	Unable to reject
Northeast	3.937	10,286	1.86	Reject	7.173	10,286	1.86	Reject	8.878	10,286	1.86	Reject

Table 3: Northern Plains: Instrumental Variable with Autocorrelation Estimates of Nash-Cournot Demand for Public Agricultural Research, 1951-1985 (t-ratios in parentheses)

		Regressors			
States	$\hat{\rho}$	Constant	$\ln P^{*}_{xt}$	$\ln \bar{F}_{it}$	$\ln SPILL^{r}_{it}$
Kansas	-	-10.611 (-4.88)	-2.592 (-1.38)	0.755 (1.87)	-0.831 (-1.66)
Nebraska	-	-13.270 (-10.78)	-5.016 (-3.74)	0.244 (0.65)	1.478 (4.05)
North Dakota	-	-11.094 (-5.80)	-4.232 (-6.79)	0.210 (12.21)	1.3889 (10.07)
South Dakota	-	-15.170 (-8.53)	-6.177 (-8.85)	-0.069 (-0.56)	1.874 (9.93)

Table 4: West: Instrumental Variable with Autocorrelation Estimates of Nash-Cournot Demand for Public Agricultural Research, 1951-1985. (t-ratios in parentheses)

States	$\hat{\rho}$[a]	Constant	$\ln P^*_{xt}$	$\ln\bar{F}_{it}$	$\ln SPILL^r_{it}$
		Regressors			
Arizona	-	-3.390 (-4.43)	-1.377 (-5.76)	0.561 (32.35)	0.564 (11.28)
California	-	-5.453 (-4.17)	-1.961 (-4.18)	0.416 (9.32)	0.787 (7.22)
Colorado	0.37	-1.808 (-2.51)	-0.957 (-2.66)	0.661 (17.09)	0.442 (5.89)
Idaho	-	-5.167 (-6.88)	-1.587 (-6.60)	0.725 (30.55)	0.551 (10.71)
Montana	0.41	-2.833 (-3.82)	-2.178 (-6.17)	0.419 (14.41)	0.769 (10.21)
Nevada	-	-4.398 (-4.05)	-2.068 (-6.33)	0.489 (23.39)	0.688 (10.19)
New Mexico	0.54	0.458 (0.48)	1.023 (1.25)	1.156 (6.58)	-0.180 (-0.91)
Oregon	-	-4.803 (-5.68)	-1.280 (-4.65)	0.648 (27.91)	0.582 (10.35)
Utah	-	-4.163 (-3.73)	-1.695 (-4.83)	0.581 (20.53)	0.593 (7.99)
Washington	-	-6.661 (-8.69)	-1.811 (-7.37)	0.645 (28.78)	0.660 (12.79)
Wyoming	-	0.451 (0.37)	-0.341 (-0.85)	0.738 (20.04)	0.202 (2.32)

[a] When statistically significant first-order autocorrelation occurs, $\hat{\rho}$ is used to transform the data.

Table 5. Northeast: Instrumental Variable with Autocorrelation Estimates of Nash-Cournot Demand for Public Agricultural Research, 1951-1985. (t-ratios in parentheses)

		Regressors			
States	$\hat{\rho}$[a]	Constant	$\ln P^{*}_{xt}$	$\ln \bar{F}_{it}$	$\ln SPILL^{r}_{it}$
Delaware	-	21.211 (5.00)	1.894 (2.17)	0.323 (4.31)	-0.922 (-3.71)
Connecticut	-	-7.318 (-1.77)	-1.208 (-1.82)	0.563 (18.14)	0.873 3.28)
Massachussetts	-	-14.606 (-3.11)	-1.899 (-2.65)	0.642 (16.33)	1.291 (4.33)
Maryland	-	6.840 (3.58)	0.550 (1.70)	0.486 (14.69)	-0.073 (-0.68)
Maine	-	-12.938 (-2.99)	-1.565 (-2.39)	0.745 (16.74)	1.154 (4.25)
New York	-	7.053 (3.22)	0.335 (0.79)	0.451 (14.48)	-0.134 (-1.05)
New Jersey	-	7.109 (3.12)	0.391 (1.02)	0.412 (13.88)	-0.035 (-0.27)
Pennyslvania	-	7.635 (3.23)	0.628 (1.52)	0.502 (12.54)	-0.196 (-1.49)
Rhode Island	-	-10.791 (-2.63)	-1.705 (-2.69)	0.638 (17.61)	1.076 (4.13)
Vermont	0.44	-0.965 (-0.53)	-0.885 (-2.04)	0.568 (13.54)	0.491 (2.41)
New Hampshire	-	-6.781 (-1.58)	-1.376 (-2.04)	0.595 (16.13)	0.836 (3.07)

[a] When statistically significant first-order autocorrelation occurs, $\hat{\rho}$ is used to transform the data.

Table 6. Central Region: Instrumental Variable with Autocorrelation Estimates of Nash-Cournot Demand for Public Agricultural Research, 1951-1985. (t-ratios in parentheses)

States	$\hat{\rho}$ [a/]	Regressors: Constant	$\ln P^{*}_{xt}$	$\ln \bar{F}_{it}$	$\ln SPILL^{r}_{it}$
Indiana	-	-6.368 (-11.12)	-1.537[b/] (-11.19)	0.701 (25.97)	0.596[c] (19.64)
Illinois	-	-4.505 (-8.01)	-1.537[b/] (-11.19)	0.542 (21.68)	0.596[c/] (19.64)
Iowa	-	-6.995 (-12.06)	-1.537[b/] (-11.19)	0.766 (27.43)	0.596[c/] (19.64)
Michigan	-	-5.978 (-10.49)	-1.537[b/] (-11.19)	0.636 (26.61)	0.596[c/] (19.64)
Missouri	0.71	0.107 (0.23)	-1.537[b/] (-11.19)	0.272 (1.85)	0.596[c/] (19.64)
Minnesota	-	-4.798 (-8.12)	-1.537[b/] (-11.19)	0.589 (20.31)	0.596[c/] (19.64)
Ohio	-	-5.149 (-10.34)	-1.537[b/] (-11.19)	0.583 (36.02)	0.596[c/] (19.64)
Wisconsin	-	-3.56 (-5.03)	-1.537[b] (-11.19)	0.502 (12.82)	0.596[c/] (19.64)

[a/]When statistically significant first-order autocorrelation occurs, $\hat{\rho}$ is used to transform the data.

[b/], [c/]Coefficients were restricted to be equal across states.

Table 7. Restricted Two-Stage Least Squares Estimates of Nash-Cournot Demand for Public Agricultural Research, 1951-1985. (t-ratios in parentheses)

Regions	Regressors		
	$\ln P^{*}_{xt}$	$\ln \bar{F}_{it}$	$\ln SPILL^{r}_{it}$
South and Eastern Uplands	-2.013	0.518	0.699
	(-25.17)	(46.14)	(47.93)
Southern	-2.129	0.741	0.707
	(-6.23)	(23.41)	(7.89)